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COMPETITION UNDER REGULATION: DO REGULATED GAS TRANSMISSION SYSTEM OPERATORS IN MERGED MARKETS COMPETE ON NETWORK TARIFFS?

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Abstract

In Europe, gas market mergers take place to reduce restrictions between gas wholesale markets. After a merger, transport capacity of multiple gas transmission system operators (TSOs) may be offered as substitutes, which may result in competition among TSOs. Based on a theoretical analysis, we determine the optimal set of tariffs for TSOs considering different regulatory regimes. Applying a panel data analysis to tariffs charged at German border points between 2015 and 2018, we find lower tariffs at those border points at which network users have a choice between different TSOs. A differentiation between transit and meshed networks does not provide a sufficient explanation for this finding. Further research is required to analyse how TSOs consider the existence of substitutes for network users in setting tariffs.

Key Words:

Gas market, Tariff Regulation, Competition, Market merger

JEL Codes:

D47, K23, L51, L95, L98, Q48

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1 Introduction

From an economic perspective, natural monopolies have a need for regulation. In absence of effective competition, regulation ensures that the monopolist does not exploit its market power, e.g. by charging monopoly prices, and may also be more focused on the quality of its services. Such monopolists are often infrastructure operators.

In gas markets, transmission and distribution networks are viewed to be natural monopolies, and, hence, are regulated. Transmissions networks, operated by transmissions system operators (hereafter: TSOs), connect all major players and infrastructures of the gas market. Therefore, they are said to be the backbone of gas markets facilitating wholesale markets. In Europe, there are gas market areas organised as so-called *entry-exit systems*, which also allows for cross-border trade. In order to reduce obstacles to trade, and increase wholesale market liquidity and competition, gas markets become integrated, in particular, by market mergers (ACER and CEER, 2015).

Besides the impact on wholesale markets, market mergers can also have an impact on incentives for gas TSOs. If, after a merger of market areas, two TSOs operating in the same market area are connected to the same adjacent market area, network users obtain transport substitutes. Such opportunity results from gas markets being organised as entry-exit systems (Lohmann, 2009). In an entry-exit system, network users acquire transmission capacity at network points to inject and withdraw gas from any network of the respective market. As a consequence, if more than one TSO belongs to the same market area and are connected to the same adjacent market offering transport capacity, network users have a choice between a number of TSOs (Keller et al., 2019).

The existence of substitutes to network users acquiring gas transport capacity requires them to make a choice, at which TSO to book transport capacity. Thus, market mergers may imply inter-TSO competition. However, such a competition may only be possible if the behaviour of the demand side, i.e. network users' behaviour, is efficient. Keller et al. (2019) analysed the behaviour of network users booking gas transport capacities offered by multiple TSO, which are substitutes. Measuring the efficiency of booking transport capacities at cross-border interconnection points offered as substitutes by multiple TSOs, they find network users are sensitive to the difference in prices of capacity. Based on this, they conclude that market mergers have the potential to create inter-TSO competition on tariffs given an efficient booking behaviour of network users.

A price-sensitive booking behaviour is a prerequisite for inter-TSO competition. However, such finding is not sufficient to conclude inter-TSO competition exists. As TSOs are regulated entities, the possibilities and incentives to engage in tariff competition are determined by the regulatory regime applied. Therefore, it is necessary to analyse how TSOs in merged market areas set tariffs keeping in mind an efficient booking behaviour of the participants on the demand side, and the regulatory regime applied.

In the literature, there are a number of regulatory regimes for tariff setting applied to energy networks, which differ in incentive power and level of profits allowed (Arcos-Vargas et al., 2017). Armstrong and Sappington (2006) examined how to introduce competition in regulated industries finding that an optimal liberalisation process highly depends on the institutional setting. In the case of the liberalisation of the British gas market, they show that allowing for competition in regulated industries often refers to activities such as production and supply of utilities, and not directly to competition between infrastructures. Vogelsang (2002) assessed the competitive role of price-cap regulation and horizontal competition, and found that price-caps allow for *regulation cum competition*, given the flexibility they offer in setting prices for regulated output of a firm. However, the presence of (potential) competitors is required to introduce competition to a monopolist, which requires a contestable market and free market entry (Baumol, 1982). Laffont and Tirole (1996) examined potential competition between an integrated incumbent owning telecommunication networks and new entrants. Their work aims to find the optimal access charge to the essential facility so that the incumbent and the new entrant can compete in providing unregulated telecommunication services. They claim a duplication of a network, noting that this is associated with high costs, may be justified as it may allow for competition. Studies and research intending to contribute explicitly to the future tariff regulation in European gas markets do not take into account the role of market mergers with regard to the potential for inter-TSO competition. Instead, these studies suggest applying zero tariffs at borders between gas markets, and recovering revenue shortfalls at other network points, or setting up a compensation scheme (Cervigni et al., 2019; EY and REKK 2018; Hecking, 2015).

Our paper extends the literature on (de-)regulation of natural monopolists. It has a different view as compared to other work, as the potential competition arises from merging markets with regulated monopolists, and does not arise from unregulated new entrants in the market. In contributing to the future of tariff regulation in European gas markets, our focus differs from other studies and research, which do not take account of market mergers and their impact on the potential for inter-TSO.

This paper investigates tariff setting by TSOs under different regulatory regimes subject to market mergers. The first step in the investigation is the theoretical analysis of tariff setting under different regulatory regimes taking account of market mergers. Next, it explores empirically whether regulated TSOs in Germany consider the presence of other TSOs, being a substitute for network users, in setting tariffs.

For TSOs operating under a regulatory regime with volume risks, we find that in theory the optimal set of tariffs depends on marginal costs and price elasticities. Since a TSO’s total allowed revenues are capped, revenues to be obtained may be shifted between different network points in order to reduce the risk of not obtaining the allowed revenues granted. This is expected, in particular, if a TSO operates in a merged market area implying potential inter-TSO competition. In contrast, a TSO operating under a regulatory regime without a volume risk is supposed to have no incentives to find the optimal set of tariffs; the firm is indifferent due to the design of the regulatory framework. We perform a panel data analysis of tariffs charged between 2015 and 2018 by German TSOs, which operate under a revenue-cap regime. Such regulatory regime is characterised by absence of volume risk and the certainty to obtain allowed revenues granted. In contrast to our hypotheses, we find the tariffs are up to 52% lower in case more than one TSO offers capacity at a border, so network users obtain a choice between substitutes. An additional analysis shows that a differentiation between transit and meshed networks does not provide a sufficient explanation for this result. Hence, we conclude that even in the case of revenue regulation mergers of market areas may have an influence on tariff setting.

Following this introduction, the paper starts with describing how European gas markets are designed, how transmission networks are commercially operated, how market mergers impact gas markets and market players, and how tariff regulation can be designed (Section 2). Section 3 continues with the theoretical framework finding the optimal set of tariffs of a TSO under different regulatory regimes and market structures. The hypotheses obtained from the theoretical analysis are tested in Section 4. Section 5 provides our conclusions and related discussions.

2 Background

2.1 TSOs, network points, and market mergers

A transmission system operator offers transmission services using a gas pipeline network. Transmission refers to the transport through a mainly high-pressure infrastructure not aimed at a direct local distribution, and not including other activities than gas transport, e.g. production or storage. A TSO offers the use of a network by offering transport capacity to the market. Such capacity is demanded by so-called *network users* being, for example, gas traders or suppliers (European Parliament and Council of the European Union, 2009).

Capacity is offered at network points, and can be referred to as the right of a network user to inject or withdraw gas. Injection and withdrawal of gas within a TSO's network are independent from each other. The so-called *entry-exit system* allows a network user to inject (entry) gas at any point of the network, and to withdraw (exit) gas at any other point of the same network. The transport is the sole responsibility of the network operator. A TSO network, therefore, may also be referred to as an entry-exit system or a market area.

There are two categories of network points: *Interconnection points* (hereafter: IPs) connect two market areas (European Commission, 2017a). This means, IPs connect two adjacent TSOs' networks in different market areas. In practice, these IPs are usually located at the border between countries allowing for cross-border trades and flows. If a country has more than one market area, IPs also exists within a country. All other network points, which are not located at a border, are referred to as domestic points. These include, for instance, production sites, storage facilities, industrial customers, and networks for the purpose of local distribution.

Based on the entry-exit system, gas wholesale market could evolve (Vazquez et al., 2012). In order to improve the functioning of wholesale markets, e.g. increasing liquidity and competition among trading companies, market areas may be merged (ACER and CEER, 2015). As a result of two market areas merging, the resulting new market area consists of more than one TSO.[1] In addition to effects on wholesale markets, market mergers create transport alternatives to network users in case two TSOs belong to the same market area, and each has an IP connecting the same adjacent market area (Keller et al., 2019). This is illustrated in Figure 1. There is a market area MA ABC, which is a merged one. This market area consists of networks operated by three different TSOs, namely A, B, and C.[2] Prior to the merger, each TSO operated one market area individually. In the merged market, there are seven IPs, operated by different TSOs and connected to different adjacent markets areas. TSOs A and B also have domestic points connected to their network, whereas TSO C only operates IPs. MA ABC is connected to four adjacent market areas, i.e. MA 1 to MA 4. Focussing on transport substitutes, which may allow for inter-TSO competition, TSO A is the only supplier of capacity to and from MA 1.[3] At the border with MA 2, there are two IPs, namely A2 and B1. In booking capacity, a network user is free to choose either of the two. The same holds at the border with MA 3. As compared to this, the situation at the border with MA 4 is different. A network user is free to book

[1] It is conceivable that TSOs in the new, merged market area belong to the same parent company, which may affect their competitive behavior. We assume that this is not the case, and the TSOs are separate companies, which is generally the case.

[2] Note that the focus is on commercial aspects. Hence, physical pipelines are not relevant because the market areas are designed as entry-exit systems, and, therefore, omitted in the figure.

[3] For simplicity, we assume all IPs are bi-directional, i.e. offering capacity between MA ABC and the respective adjacent market area in both flow directions.

capacity at IPs C2 or C3, however, both are operated by TSO C. Nevertheless, the two IPs are still substitutes from a network user's point of view.

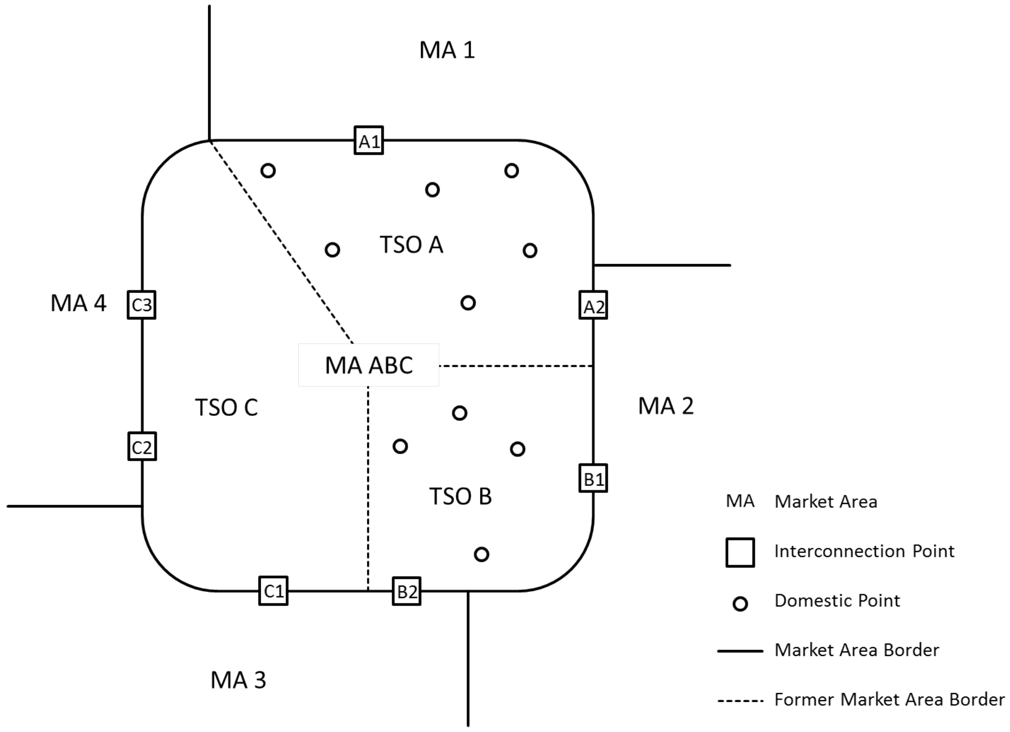

Figure 1: Stylised commercial relationship of TSOs, borders of market areas, and network points

Whereby substitutes may arise at borders, domestic points are usually connected to just one transmission network. While TSOs A and B have domestic points, TSO C does not. The majority of domestic points refer to end-customers. On the one hand, there are industrial customers like energy intensive industries and gas fired power plants, which are directly connected to a transmission network. On the other hand, households are connected to distribution networks, which are connected to transmissions networks. Hence, households are indirectly connected to transmission networks. Following this, the demand for capacity inducing flows from transmission networks to distribution networks is derived from the demand of end-customers.

End-customers can be referred to as captive demand, as these are characterised by a relative inelastic demand. For households, gas is usually used for cooking and heating. Once a cooking facility or heating system has been installed, the household is locked-in into this technology. Although, for example, additional insulation, and changes in behaviour may lead to a lower demand for gas, there are still high switching costs related to a full fuel switch. The same applies to industrial customers, who, to a certain extent, may have the ability to switch fuels.

2.2 Tariff determination

Microeconomic theory assumes that companies aim at profit maximisation. This holds irrespective of the structure of a market, whether it is characterised by a monopoly or perfect competition. Hence, this theory also holds for gas transmission system operators, which operate an infrastructure characterised by a natural monopoly. Since TSOs are natural monopolists facing no effective competition, they are regulated. Regulation of European TSOs mainly consists of network access regulation and tariff regulation supported by ownership unbundling provisions.

Tariff regulation determines how much a regulated TSO is entitled to earn. In principle, determining the allowed revenues includes consideration of realised investments, i.e. capital expenditures (CAPEX), into the infrastructure, as well as the costs to operate and maintain the infrastructure, i.e. operational expenditures (OPEX). As part of the capital expenditures, an appropriate return on capital ensures a firm is willing to operate the business and makes the necessary investments. In the literature, there are a number of different regulatory regimes, which are either cost-based (e.g. cost-plus and rate-of-return regulation) or incentive-based (e.g. price-cap, revenue-cap, and yardstick regulation) regimes (Arcos-Vargas et al., 2017). The difference refers to how the allowed revenues are related to the firm's costs, which leads to different incentives for the regulated firm (see for example Braeutigam and Panzar, 1989; Cabral and Riordan, 1989; Averch and Johnson, 1962). Regardless of the regulatory regime applied, the regulated TSO is given a revenue cap[4] determining how much the firm is entitled to earn.

After it has been determined how much a TSO is entitled to earn (R^a), the second aspect of tariff regulation refers to how the TSO obtains its allowed revenues by generating expected revenues from the forecasted (superscript *f*) sales of capacity products at different network points, IPs as well as domestic ones, ($i = 1, \dots, n$), at a tariff applicable to network point *i*. In this respect, the revenue cap constraint in Equation (1) is binding to the TSOs.[5]

$$R^a = \sum_{i=1}^{n} capacity\ bookings_i^f \times tariff_i \tag{1}$$

According to the revenue cap constraint, a TSO is granted a level of allowed revenues for a specific period, which must not be exceeded by the expected revenues obtained from expected capacity sales and the tariffs applicable.[6] Given a revenue cap constraint, tariff optimisation of a TSO can be referred to as finding the optimal set of tariffs, i.e. a tariff for all network points of a TSO, which maximises profits.[7] As the regulatory authority regulates the total revenues, it is assumed that TSOs are free to choose any set of tariffs as long as the revenue cap constraint is considered. This allows TSOs to shift revenues to be obtained from one network point to another. To illustrate this, assume there are two network points with equal capacity bookings and tariffs. Total revenues obtained from these two network points do not change if one tariff is decreased while the other tariff is increased by the same amount. This implies that if one tariff increases (decreases), at least one other tariff has to decrease (increase) to comply with the revenue cap constraint. This possibility of *revenue shifting* between network points allows for flexibility in finding the optimal set of tariffs.

[4] Note that different terms may be used under different regulatory regimes, like allowed revenues or target revenues. Although there are differences in detail, all of them refer to the fact that regulation grants a certain level of revenues to be obtained by the TSO.

[5] Although tariffs are determined at a particular point in time for a particular period in the future, tariff calculation is static. To calculate tariff applicable in *t*, also the allowed revenues and the capacity forecast valid for *t* are used. Hence, it is not necessary to consider a time dimension, which is therefore dropped for simplicity.

[6] Note that tariff calculation takes places prior to the tariff period, i.e. the period in which the tariffs are valid. Hence, the value for capacity bookings is always a forecasted one.

[7] This needs to be distinguished from a regulation of profits. The profits a TSO can obtain are related to the regulatory regime applied. For example, under rate-of-return regulation, in principle a TSO cannot raise its profits by choosing different tariffs. Under incentives regulation, a TSO may earn temporary extra profits by cost reductions exceeding efficiency targets set by the regulatory authority. However, once the total allowed revenues are determined, the revenue cap constraint is binding in setting tariffs.

Since the capacity bookings and revenues in Equation (1) include both capacities from IPs as well as capacities from domestic points, revenue shifting may take place not only inside a group of network points but also between them.

The allowed revenues are set by a regulatory authority, so, from a TSO's point of view, they are exogenously given. Then, according to Equation (1), tariffs are derived given the allowed revenues and capacity forecasts. Regarding forecasted capacity bookings used as an input to determine tariffs, two cases can be distinguished. Firstly, the regulatory authority, based on information provided by the TSO, makes a capacity forecast, or at least prescribes a methodology how the TSO has to forecast capacity bookings. The TSO has the incentive to underestimate the capacity demand: If actual bookings exceed the forecasted bookings, the TSO obtains extra revenues and profits. Therefore, it is necessary for the regulatory authority to control and/or set clear rules as how to forecast capacity bookings. If the expected volumes are based on, for instance, historical data, the TSO may argue in discussions with the regulatory authority that the resulting tariffs have an effect on demand so that the forecast needs to consider this. This is referred to as information asymmetries, since the TSO has a more detailed insight into market reactions than the regulatory authority. Such additional information may be an advantage in negotiating with the regulator about the forecasted capacity bookings to be used in determining tariffs. Such an approach is characteristic for a price-cap regime (Beesley and Littlechild, 1989; Sibley, 1989).

Secondly, a regulatory authority may give freedom to the regulated TSO to forecast capacity bookings. This comes with the advantage that no interaction between the regulatory authority and the regulated TSO regarding the capacity forecast is necessary. Hence, it also overcomes the problem of information asymmetry. In this situation, ceteris paribus, lower capacity forecasts can be expected as this leads to an increase in TSOs revenues. Such an approach is characteristic for a revenue-cap regime, which imposes a maximum of allowed revenues (Arcos-Vargas et al., 2017). To avoid lower capacity forecasts to increase revenues, a TSO under a revenue-cap regime is not entitled to keep extra revenues obtained, i.e. the revenues exceeding the level of allowed revenues, the so-called *over-recoveries*. After a tariff period, the over- or under-recovery is tracked in a so-called *regulatory-account*. This regulatory account is reconciled in future periods. This is discussed in more detail in Section 3.2.

As this discussion shows, it is necessary to distinguish between two types of regulatory regimes, in order to find the optimal set of tariffs for a TSO. There are regulatory regimes that imply a volume risk to the regulated firm, e.g. a price-cap regime, and those that do not imply a volume risk, e.g. a revenue-cap regime. A TSO operating under a price-cap regime takes a volume related risk. To compensate for the risk, the over-recoveries can be kept, which is why the TSO has the incentive to make use of information asymmetries, and forecast too low capacity bookings in order to obtain extra revenues. On the other hand, there are revenue-cap regimes under which a TSO is not exposed to any volume related risk. Hence, there are also no extra revenues, which can be kept. This is without any risk so that the TSO is ensured obtaining the allowed revenues, which the firm is not ensured in case of a price-cap regime.

3 Theoretical framework

In the following, we assess the optimal tariff setting behaviour of a regulated TSO. Our approach is motivated by Joskow (2007), and Laffont and Tirole (2000). Based on Section 2.2, a distinction is made between the regulated regimes applied to the TSO. Section 3.1 finds the optimal tariff set for a single TSO exposed to a volume risk, Section 3.2 for a single TSO without any volume risk. Since a

TSO is regulated in both cases, the total allowed revenues are capped. Hence, in finding the optimal set of tariffs, the revenue cap constraint is binding in both cases. In Sections 3.3 and 3.4, the setting is changed so that not only one TSO is offering capacity but network users have a choice between IP capacities offered by multiple TSOs, i.e. substitutes.

This paper focusses on the impact of the general regulatory regime applied, and the impact of market mergers on the tariff setting behaviour of TSOs. However, we acknowledge there may be other aspects related to the actual regulatory regime applied that may give further (dis-)incentives to TSOs in setting tariffs. As stated in Section 2.2, TSOs are assumed to be free to choose any tariff as long as the revenue cap is not violated. In practise, it may be possible that the regulatory authority restricts this freedom. In the conclusion section we will discuss other factors that potentially affect tariff setting behaviour of TSOs.

3.1 Optimal set of tariffs of a single TSO with a revenue cap constraint and a volume risk

Assume there is a market area, which has not been affected by any market mergers, and in which there is only one single firm operating one transmission system. Furthermore, assume this firm operates under a price-cap regime, so that it is exposed to a volume risk. The TSO offers capacity $x_i > 0$ at network points $i = 1, \ldots, n$, and sets tariffs $t_i \geq 0$. Furthermore, the TSO is assumed not to be allowed to restrain the amount of capacity on offer, so that the maximum capacity on offer at a particular network point is x_i, and is exogenously given. This implies that the offer of capacity at one point does not affect the amount offered at any other network point so that $\frac{\partial x_i}{\partial x_j} = 0$, if $i \neq j$. The TSO offers a capacity vector $\vec{x}$ at a tariff vector $\vec{t}$. The demand function is $\vec{q} = D(\vec{t})$, its inverse demand is $\vec{t} = D^{-1}(\vec{q})$, with a slope $\beta_i = \frac{\partial t_i}{\partial q_i} < 0$ at each network point. The inverse demand function implies that in setting tariffs at a point *i* the TSO considers the tariffs set at all other network points, to which revenues to be obtained may be shifted.[8]

Total revenues obtained of the TSO are $R = \sum_{i=1}^{n} q_i t_i$. Total costs are $C = C(q_1, \ldots, q_n)$, allowing marginal costs to differ for each network point. Price elasticity of demand at point $i = 1, \ldots, n$ is defined as $\varepsilon_i = \frac{\partial q_i}{\partial t_i} \times \frac{t_i}{q_i} < 0$. The TSO maximises profits $\pi = R - C$ subject to the revenue cap constraint and the capacity constraints at each network point, and considers the possibility to shift revenues between network points:

$$\max_{q_1, \ldots, q_n} R - C$$
$s.t. R \leq R^a$, and $q_i \leq x_i$, for all *i* = 1,...,*n*.

The Lagrangian function is:
$$L(q_1, \ldots, q_n, \lambda, \mu_1, \ldots, \mu_n) = R - C - \lambda(R - R^a) - \sum_{i=1}^{n} \mu_i (q_i - x_i).$$

The first-order conditions are:
$$\frac{\partial L}{\partial q_i} = \frac{\partial R}{\partial q_i} - \frac{\partial C}{\partial q_i} - \lambda \left(\frac{\partial R}{\partial q_i}\right) - \mu_i = 0, \text{ for all } i.$$

The complementary slackness conditions are:
$\lambda \geq 0$, with $\lambda = 0$ if $R < R^a$, and

[8] The response to tariffs set by other TSOs is dealt with in the next section.

$\mu_i \geq 0$, with $\mu_i = 0$ if $q_i < x_i$.

Rewriting the first-order conditions yield:
$(1-\lambda)\frac{\partial R}{\partial q_i} = \frac{\partial C}{\partial q_i} + \mu_i \Rightarrow \frac{\partial R}{\partial q_i} = \frac{1}{1-\lambda}\left(\frac{\partial C}{\partial q_i} + \mu_i\right)$, if $\lambda \neq 1$.

We assume that second-order conditions are negative, so the Lagrangian is concave.[9]

In order to derive optimal tariffs, solve

$$\begin{aligned}
\frac{\partial R}{\partial q_i} &= \sum_{j=1}^{n} \frac{\partial q_j}{\partial q_i} t_j + \sum_{j=1}^{n} q_j \frac{\partial t_j}{\partial q_i} \\
&= t_i + \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{\partial q_j}{\partial q_i} t_j + q_i \frac{\partial t_i}{\partial q_i} + \sum_{\substack{j=1 \\ j\neq i}}^{n} q_j \frac{\partial t_j}{\partial q_i} \\
&= t_i + \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{\partial q_j}{\partial q_i} t_j + \frac{t_i}{\varepsilon_i} + \sum_{\substack{j=1 \\ j\neq i}}^{n} q_j \frac{\partial t_j}{\partial q_i} \frac{q_i}{q_i} \frac{t_j}{t_j} \\
&= t_i + \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{\partial q_j}{\partial q_i} t_j + \frac{t_i}{\varepsilon_i} + \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{t_j}{\varepsilon_{i,j}} \frac{q_j}{q_i} \\
&= \left(1 + \frac{1}{\varepsilon_i}\right) t_i + \sum_{\substack{j=1 \\ j\neq i}}^{n} \left(\frac{\partial q_j}{\partial q_i} + \frac{1}{\varepsilon_{i,j}} \frac{q_j}{q_i}\right) t_j,
\end{aligned}$$

where $\varepsilon_i = \frac{\partial q_i}{\partial t_i} \times \frac{t_i}{q_i} < 0$ and $\varepsilon_{i,j} = \frac{\partial q_i}{\partial t_j} \times \frac{t_j}{q_i} \neq 0$. The latter term is a cross-elasticity, which is positive in case of substitutes. It shows the change in demand at network point *i* in relation to a change in tariffs at another network point *j* of the same TSO.

Combining with $\frac{\partial R}{\partial q_i} = \frac{1}{1-\lambda}\left(\frac{\partial C}{\partial q_i} + \mu_i\right)$, assuming $\lambda \neq 1$, gives:

$$\left(1 + \frac{1}{\varepsilon_i}\right) t_i + \sum_{\substack{j=1 \\ j\neq i}}^{n} \left(\frac{\partial q_j}{\partial q_i} + \frac{1}{\varepsilon_{i,j}} \frac{q_j}{q_i}\right) t_j = \frac{1}{1-\lambda}\left(\frac{\partial C}{\partial q_i} + \mu_i\right).$$

Assuming a relative elastic demand $\varepsilon_i < -1$ and $0 \leq \lambda < 1$ to ensure a positive relation between tariffs and marginal costs, the optimal tariff applicable at network point *i* is given by Equation (2).

$$t_i^{optimal} = \frac{\varepsilon_i}{\varepsilon_i + 1}\left[\frac{1}{1-\lambda}\left(\frac{\partial C}{\partial q_i} + \mu_i\right) - \sum_{\substack{j=1 \\ j\neq i}}^{n} \left(\frac{\partial q_j}{\partial q_i} + \frac{1}{\varepsilon_{i,j}} \frac{q_j}{q_i}\right) t_j\right] \quad (2)$$

According to Equation (2), an optimal tariff, which is applicable at a network point *i*, and which is part of the optimal set of tariffs of a TSO, is determined by three components; the elasticity of

[9] If the cost function is linear, a sufficient condition for the Lagrangian to be concave $\left(\frac{\partial^2 R}{\partial q_i^2} < \frac{1}{1-\lambda}\frac{\partial^2 C}{\partial q_i^2} < 0\right)$, is a concave revenue function, that is $\frac{\partial R}{\partial q_i} > 0$ and $\frac{\partial^2 R}{\partial q_i^2} < 0$.

demand ε_i, marginal cost $\left(\frac{\partial C}{\partial q_i} + \mu_i\right)$, and the interaction between network points of the same TSO, $\sum_{\substack{j=1 \\ j \neq i}}^{n} \left(\frac{\partial q_j}{\partial q_i} + \frac{1}{\varepsilon_{i,j}} \frac{q_j}{q_i}\right) t_j$. The third component of an optimal tariff consists of two terms. The first one refers to the revenue shifting effect $\left(\frac{\partial q_j}{\partial q_i} < 0\right)$. The second term consists of two factors. In case of substitutes, the elasticity of two goods is always positive. This is the case here, as points *i* and *j* are substitutes in terms of obtaining revenues. Hence, $\frac{1}{\varepsilon_{i,j}}$ is always positive; also $\frac{q_j}{q_i}$ is positive, since capacity demand is always positive. Therefore, if $\frac{\partial q_j}{\partial q_i}$ is not too negative, the sum of the terms that constitute the third component is positive, which indicates that the optimal tariff for network point *i* is lower the more revenues the TSO obtains from all points *j*; i.e. the higher the revenue shifting effect.

Without the possibility of revenue shifting, $\frac{\varepsilon_i}{\varepsilon_i+1} \frac{1}{1-\lambda} \left(\frac{\partial C}{\partial q_i} + \mu_i\right)$ represents the optimal tariff of a network point with $\varepsilon_i < -1$ and $0 \leq \lambda < 1$. Such tariffs are known as *Ramsey prices* (Ramsey, 1927). With $\varepsilon_i < -1$ and $0 \leq \lambda < 1$, higher marginal costs are related to higher tariffs. The higher the elasticity of demand, the lower the mark-up on the marginal costs.

It follows from Equation (2) that optimal tariff have a lower boundary, which is equal to marginal costs $\left(\frac{\partial C}{\partial q_i} > 0\right)$. On the other hand, a firm enjoying a monopoly would not set a tariff exceeding the monopoly tariff. In case of a monopoly tariff at network point *i*, it holds that $\frac{\partial R}{\partial q_i} = \frac{\partial C}{\partial q_i} > 0$. Thus, the first-order conditions are: $\frac{\partial L}{\partial q_i} = \lambda \left(\frac{\partial R}{\partial q_i}\right) - \mu_i = 0$, for all *i.*

The complementary slackness conditions are:
$\lambda \geq 0$, with $\lambda = 0$ if $R < R^a$, and
$\mu_i \geq 0$, with $\mu_i = 0$ if $q_i < x_i$.

Rewriting the first-order conditions yields $\frac{\partial R}{\partial q_i} = -\frac{\mu_i}{\lambda} \leq 0$. This result is not consistent with positive marginal returns. Hence, it holds that the optimal tariff to be set by a TSO for a network point *i* lies within a range with the lower boundary being equal to marginal costs (*MC*), and the upper boundary being the monopoly tariff: $MC \leq t_i^{optimal} < t_i^{monopoly}$.

3.2 Optimal set of tariffs of a single TSO with a revenue cap constraint and without a volume risk

As compared to Section 3.1, assume the TSO operates not under a price-cap regime but under a revenue-cap regime. As highlighted in Section 2.2, the difference between the two regimes is that the former is associated with a volume risk, i.e. the risk of under-recoveries, and the chance for over-recoveries, which directly impacts a firm's revenues. Under a revenue-cap regime, there is no volume risk for the regulated firm, as over- and under-recoveries are tracked on a regulatory account (*RA*) after each tariff period (*t*), to be reconciled in the future.[10] The regulatory account is defined as

[10] Since *t* is typically used as the time index, which from now on becomes important in the paper, we as of now use *t* to refer to a tariff period, and let *T* denote tariffs, to avoid confusion.

$$RA_t = \left[RA_{t-1} + \sum_{i=1}^{n}\left(Q_{i,t}^{f} - Q_{i,t}^{r}\right)\times T_{i,t}\right]\times(1+i), \tag{3}$$

RA is the regulatory account balance, Q^f and Q^r represent forecasted and realised capacity bookings, *T* is the tariff, and *i* is the interest rate. Since the regulatory account tracks differences over time, its basis is the last account's balance. In case the reconciliation period is equal to one tariff period, this value is zero. The second term is the difference in forecasted and realised capacity bookings multiplied by the respective tariff applicable, for all network points of a TSO. This term refers to the over- or under-recovery

Assume a TSO under a revenue-cap regime has a regulatory account, which is fully reconciled in the next tariff period, and there are no other changes to the allowed revenues, then Equation (3) reduces to $R_t^a = R_{t-1}^a + RA_{t-1}$. Thus, regardless of tariffs applied, and irrespective of the actual capacity bookings, the TSO does not take any revenue risk.[11] Nevertheless, the revenue cap constraint is binding. If the TSO forecasts too low capacity bookings on purpose, tariffs will be higher. If these higher tariffs are applied and the actual bookings exceed the forecasted ones, than, like under a price-cap regime, the TSO obtains revenues exceeding the allowed revenues; the TSO ends up with an over-recovery. However, it is the nature of a regulatory account to balance over- and under-recoveries. In case of over-recoveries, the regulatory account redistributes the over-recovery to network users by lowering the TSO's future allowed revenues, which leads to lower future tariffs. Therefore, TSOs operating under a regulatory regime without facing any volume risk, e.g. revenue-cap regime, do not have an incentive to adjust tariffs in order to increase revenues, as there are ultimately no additional revenues for the TSOs to keep. Based on this, we conclude there is no profit-maximising set of tariffs in this setting. Nevertheless, the question remains how tariffs are set in such a case.

If there are no direct profit-maximizing arguments for setting tariffs, there needs to be another rationale. EU tariff regulation, which is the result of a process with high stakeholder involvement, states that the methodology to derive tariffs shall be transparent, i.e. comprehensible, cost-reflective, non-discriminatory for different groups of customers, i.e. preventing cross-subsidisation and volume related risks, and shall not distort cross-border trade of gas (European Commission, 2017b). The most comprehensible methodology used to set tariffs is referred to as a *postage stamp methodology* (ACER, 2013). Applying such, tariffs are determined by $T_i = T = \frac{R^a}{\sum_{i=1}^{n} Q_i^f}$. As a result, there is a uniform tariff applicable to every unit of capacity, regardless of the network point this capacity is booked at. The methodology is very comprehensible for network users, and easy to perform by TSOs. On the other hand, such methodology might be seen as not being the most cost-reflective one. In order to take this into account, weights may be included representing cost-drivers other than capacity. Such cost drivers are, for example, the distance gas is transported. In doing so, there is no uniform tariff anymore, and the complexity increases, both for calculating the tariffs as well as understanding them.

Nonetheless, a single TSO under a revenue cap is not exposed to any tariff or volume related risk or chance, thus, there is no possibility to influence profits through tariff setting, which is why there is no profit-maximising set of tariffs for such a TSO. Hence, a TSO does not have an incentive to change tariffs in response to network users' capacity booking behaviour.

[11] In theory, finance and liquidity problems may arise in case tariffs are set that revenues received during a tariff period are not sufficient to cover operational expenditures. However, we consider this to be an extreme scenario without further relevance for this paper, and, therefore, neglect it.

3.3 Optimal set of tariffs of competing TSOs with a revenue cap constraint and a volume risk

Finding the optimal set of tariffs, the market structure has to be considered. In case there is only one single TSO offering capacity to and from adjacent gas market areas, this TSO enjoys a regulated monopoly not exposed to any competition. In such a situation, the TSO supplies the entire demand for capacity at each network point. As highlighted in Section 2, gas market mergers introduce transport alternatives at borders of gas markets, i.e. between market areas. Following this, network users requesting transport capacity have a choice between different TSOs offering transport capacity at particular borders. As found by Keller et al. (2019), network users make efficient booking decision led by differences in tariffs. Thus, such a TSO is supposed to be exposed to a certain competitive pressure at some IPs, and is not ensured serving the entire demand at a particular border. In merged markets, optimal tariffs of a TSO may not only be determined by the elasticity of demand and the possibility to shift revenues to be obtained. A TSO may also consider potential inter-TSO competition at those borders, at which substitutes exist given multiple TSOs offering capacity at the same border.

We have determined how a TSO finds the optimal set of tariffs, but it needs to be taken into account that this approach applies to all TSOs at the same time. Due to this, tariff setting needs to be regarded under game theory. The action parameter is the tariff, while the capacity amounts are fixed. Since TSOs operate as natural monopolies, we also assume no entry of new competitors in the short run. The potential inter-TSO competition is the sole result of a market merger. Furthermore, assume full transparency and no transaction costs. Additionally, we assume TSOs do not collude, so that TSOs set their tariffs as a response to each other. The regulatory regime applied shall allow for such a direct response in changing tariffs.

Assume a tariff competition game at a particular border with two TSOs on the same side of a border operating one IP each, and hence, offering capacity as substitutes. As the TSOs at first optimise their tariffs neglecting competitive pressure induced by the presence of other TSOs at the same border, the tariffs T_1, $T_2 \geq 0$ are part of the optimal set of tariffs of the two firms. Such tariffs may be adjusted in response to the competitive pressure. Let $D(T_1, T_2) = Q_1 + Q_2$ mark the total demand for capacity at that border, i.e. total demand at both IPs, as a function of the tariffs, and let X_1 and X_2 denote the capacities offered by the two TSOs at their IPs, which are limited. Such a constraint takes into account that the amount of capacity offered by a TSO is limited in the short run, and network expansions have an impact only in the longer run. Within this setting, four cases can be distinguished, which differ in terms of the capacity constraint:

1. capacity constraint is not binding:
   $D(T_1, T_2) \leq \min(X_1, X_2)$

2. capacity constraint is jointly binding:
   $D(T_1, T_2) > X_1 + X_2$

3. capacity constraint is individually binding for all players:
   $D(T_1, T_2) \leq X_1 + X_2 \ and \ D(T_1, T_2) > max(X_1, X_2)$

4. capacity constraint is individually binding for some players:
   $\min(X_1, X_2) < D(T_1, T_2) < \max(X_1, X_2)$

Case 1: Capacity constraint is not binding

In the first case, the expected total demand is lower than or equal to the maximum capacity on offer of each of the TSOs. Hence, each TSO is able to serve the entire demand on his own. Therefore, the capacity constraint is not binding so that this case is equal to one without any capacity constraints, which is known as *Bertrand competition* (Bertrand, 1883). In the simple case of a duopoly and no capacity constraints, two TSOs are in price competition, whereas the one with the lowest tariff serves the entire demand; it is an *all-or-nothing* game. Hence, demand is given by

$$D(T_1,T_2) = \begin{cases} D(T_1) & if\ T_1 < T_2 \\ D\left(\frac{T_1}{2}\right) = D\left(\frac{T_2}{2}\right) & if\ T_1 = T_2 \\ D(T_2) & if\ T_1 > T_2 \end{cases}$$

In absence of a capacity constraint, both TSOs are able to supply the entire demand with their available capacity being a homogenous, interchangeable good. If $T_2 < T_1$, all network users would book their capacity at TSO 2 as demand elasticity is supposed to be perfectly elastic. Since there is no capacity demand at TSO 1, TSO 1 is supposed to lower the tariff from T_1 to T_1', which is slightly lower than T_2. In the following, TSO 2 should respond by lowering the tariffs, causing another tariff reduction of TSO 1. As for unregulated firms, these underbidding ends when the prices are at marginal costs (*MC*), and the firm with the lower marginal costs can beat the price of its competitor. Although gas networks of the regulated TSOs, generally have marginal costs that are close to zero, they are still positive. Since either TSO is able to serve the entire demand, and as both are not willing to offer capacities at a tariff lower than marginal costs, demand should follow

$$D(t_1,t_2) = \begin{cases} D(T_1) & if\ MC_1 < MC_2 \\ D\left(\frac{T_1}{2}\right) = D\left(\frac{T_2}{2}\right) & if\ MC_1 = MC_2 \\ D(T_2) & if\ MC_1 > MC_2 \end{cases}$$

Case 2: Capacity constraint is jointly binding

In the second case, the capacity constraint is jointly binding. None of the TSO is able to serve the entire demand, neither are they jointly. Hence, a tariff reduction of, for example, TSO 1, causes a shift in demand towards TSO1 until all capacity on offer is completely sold. Until this point, demand is perfectly elastic. Once TSO 1 is fully booked, however, there are no substitutes anymore so that the remaining demand is served by TSO 2. Once there are no substitutes anymore, demand becomes more inelastic, and TSO 2 can charge a very high tariff. As compared to Case 1, the behaviour of TSOs is different. In Case 1, TSOs constantly reduced tariffs. However, in Case 2, the TSOs have an incentive to raise tariffs such that the competitor is booked first. Once the competitor is fully booked, the demand becomes more inelastic so that the second TSO can raise the tariff to obtain maximum revenues and profits taking into account the price elasticity of demand.

Case 3: Capacity constraint is individually binding for all players

In the third case, the capacity constraint is individually binding, so that neither TSO is able to serve the entire demand but both TSOs can jointly. In this case, the question is who gets which market share? This refers to a so-called *Edgeworth price cycle*. According to Edgeworth (1925), an oligopoly with capacity constraints to each of the firms does not lead to a stable equilibrium. The firms underbid the competitors' price to induce a shift of customers, with the aim of increasing market share. However, this is only rational to a certain price level, at which attracting a higher market share is associated with negative marginal revenues. At this turning point, it is rational to increase the price again. In order to maximise profits, the competitors follow. Once prices are too high, the underbidding game starts again (Maskin and Tirole, 1988). Therefore, there is no stable equilibrium, and prices are set in cycles.

Case 4: Capacity constraint is individually binding for some players

This case is related to Case 3, however, one TSO is able to serve the entire demand alone, whereas the other faces a binding capacity constraint. Thus, the TSO facing the capacity constraint may obtain capacity bookings, although, there is no guarantee to attract any, whilst the other TSO with a non-binding capacity constraint can be sure to obtain at least some capacity bookings. If TSO 1 faces the capacity constraint, and TSO 2 has enough capacity on offer to supply the entire demand alone, a stable equilibrium exists when the TSO 2 charges a very high tariff, while TSO 1 slightly underbids it. TSO 2 may try to underbid TSO 1 but this will lead to an underbidding process similar to a Bertrand competition. If TSO 2 underbids TSO 1, TSO 1 will not attract any demand, as TSO 2 offers enough capacity to supply the entire demand at a lower tariff. On the other hand, if TSO 2 grants TSO 1 a certain demand, the residual demand is served by TSO 2. The quantity may be lower but this allows for charging a higher tariff. Still, such equilibrium may only exist, if the residual demand served by TSO 2 exceeds a certain level. If the residual demand is too small, the TSO's benefit charging a very high tariff is very low compared to the loss in quantity. In such a case, a Bertrand competition may be expected, although the capacity constraint is binding for only one player of the game.

All these cases refer to an iterative process of adjusting tariffs in response to a competitor's tariff setting. In practice, however, tariff setting takes place prior to a tariff period using a forecast for demand, and tariffs may not be adjusted during the tariff period. As potential capacity constraints are relevant for the tariff setting game, a TSO also has to forecast the total demand at a particular border. Although regulation imposes wide-ranging transparency obligations on TSOs, in practice, this refers mainly to historic data. Thus, the methodology to set tariffs and information about the relevant input parameters for this methodology are not available to potential competitors at the point in time the tariffs are set. Although actual data covering the past can be considered, the assumption of full transparency does not hold in practice. Once published, tariffs may not be adjusted in response to the competitor's tariff, i.e. tariff setting in practice is not an iterative process as assumed by the cases. Following this and irrespective of any capacity constraints, Edgeworth price cycle related to TSOs setting tariffs cannot be observed in practice. The same holds for a Bertrand competition in Case 1 and potentially in Case 4. As tariffs are set prior to the tariff period and may not be adjusted during the tariff period, also Case 2 is impossible to occur in practice as this requires the adjustment of tariffs after some bookings have been made. On the contrary, a TSO, based on publicly available data and an individual learning curve, is supposed to anticipate the behaviour of other TSOs.

In anticipating the other TSOs' tariff setting behaviour, capacity constraints may be relevant. Such exist in Case 2, Case 3, and Case 4. However, as highlighted, these are *one-shot-games* associated with a risk of choosing a tariff which is, compared to the competitor and taking into account elasticities, too high or too low to generate optimal profits. Although Case 1 does not foresee any (effective) capacity constraint, this is also one-shot-game, meaning the same risks to the players.

After a market merger, a TSO may face competitive pressure related to some IPs at particular borders, because the market merger has created substitutes for the network users at this border. Equation (2) applicable to the pure monopoly case already includes an effect of substitution. Whereas in Equation (2) the effect is related to revenues being obtained at other network points of the same TSO, competition offers substitutes for networks users, and is related to revenues being obtained at the same border but by competing IPs of other TSOs. Hence, in setting an IP tariff, the respective TSO should, in addition to the revenue shifting effect, consider another substitutional effect, which is related to competitive pressure at the border the IP is located. The expectation for this effect, however, is different compared to the substitutional effect related to revenue shifting. In case of competition, the tariff of an IP is supposed to be higher (lower) the higher (lower) the tariffs of the competing IPs.

Tariff setting is, furthermore, associated with risks. A TSO not only has to forecast its own capacity bookings, but also those of the other TSOs that operate IPs at the same borders. In doing so, a TSO needs to anticipate how other TSOs might behave, and what tariffs will result from this. Keeping in mind the revenue cap constraint, this implies that not only the capacity bookings need to be forecasted, but also the allowed revenues of the potential competitors. This risk is higher the less information concerning tariff calculation is available, the higher the freedom of TSOs in setting tariffs, and the less possibility the firms have to respond to tariffs set by other TSOs. Therefore, optimising tariffs includes minimising tariff related volume risks. As shown in Figure 1, a TSO may have captive demand. Given the possibility of revenue shifting, a TSO, in theory, is able to obtain the entire allowed revenues from this captive demand. TSOs are supposed to make use of this possibility to lower tariff related volume risks.

Based on the theoretical analysis, we hypothesise that for TSOs with a binding revenue cap constraint, and which are exposed to a volume risk, their IP tariffs are lower in case substitutes for their products exist at the respective border. Ceteris paribus, we expect an IP's tariff to be lower if the corresponding TSO has the ability to shift revenues towards domestic points with captive demand. Moreover, capacity constraints, i.e. congestions, should also impact IP tariffs.

3.4 Optimal set of tariffs of competing TSOs with a revenue cap constraint and without a volume risk

Section 3.2 highlighted that for a TSO operating under a regulatory regime without a volume risk to the TSO, such as a revenue-cap regime, there is no optimal set of tariffs in absence of incentives to optimise tariffs. Hence, the TSO is supposed to be indifferent regarding tariffs. This still holds if market mergers create competitive pressure through substitute TSOs. The different cases of competition, in general, also apply to TSOs operating under a revenue-cap regime. However, as the TSOs are ensured obtaining the revenues thanks to a regulatory account, competitive pressure is supposed to be ineffective. Even the TSO that expects to lose the competition for demand has no need to adjust tariffs. The TSOs can behave like there was no competitive pressure at all, knowing the firm is ultimately ensured obtaining the revenues granted by the regulatory authority via the regulatory account.

As a result, we conclude that from a theoretical point of view no effective inter-TSO competition is likely if the TSOs operate under a revenue-cap regime.[12]

4 Empirical analysis

4.1 Empirical model

The hypotheses about optimal tariff setting derived from the theoretical analysis are tested by a panel data analysis. Tariffs are set periodically by TSOs. Therefore, panels may be created using TSOs representing the individual dimension $k = 1, \dots m,$ who set tariffs applicable at an IP located at a particular border $i = 1, \dots, n$, and being valid for a tariff period t. For each $t,$ this results in a $m \times n$ matrix. As Figure 1 highlights, not every TSO has an IP at every border. Therefore, data is not available for every TSO at every border, which is why we expect strongly unbalanced panels. To overcome this, in our model the cross-section dimension is the border *i* of gas market areas, taking into account flow directions and gas qualities. This is supposed to make the panels more balanced as there are tariffs available at every border. More information about the actual panel is presented in Section 4.2

If more than one TSO is offering capacity at a particular border, there are multiple tariffs applicable at that border at the same time. Therefore, tariffs observed cannot be used as the independent variable if the cross-section refers to borders. To be able to analyse whether certain explanatory variables lead to higher or lower tariffs, we estimate the same empirical model choosing both the minimum tariff and the maximum tariff as the dependent variable. To control for outliers, we also estimate the model using the median tariff of a border as the regressand.

The explanatory variables are derived from the hypotheses. According to this, if, from a network users' point of view, there is a possibility for substitution between IPs, and between TSOs respectively, this is expected to influence IP tariff levels. The model, therefore, includes a dummy variable dS denoting whether substitutes are available to networks users with $dS_{i,t} = 1$, if the number of TSOs offering capacity at a border *i* in *t* exceeds 1, and 0 otherwise.

According to the hypotheses, TSOs may shift revenues to be obtained towards points with captive demand, as the elasticity is expected to be lower at these points compared to IPs. Hence, it allows for avoiding competition. This is taken account of by the dummy variable $dCD_{i,t} = 1$, if the number of TSOs offering capacity at a border *i* in *t* and having captive demand exceeds 0, and 0 otherwise.

Discussing the game theoretical behaviour of TSOs setting tariffs highlighted the importance to consider congestion. Therefore, a dummy variable $dCo_{i,t}$ is included in the model to reflect this. It is defined as $dCo = 1$, if the number of congested IPs at border *i* in *t* exceeds 0, and 0 otherwise.

As the tariffs are set by regulated firms, the revenue cap constraint is binding in setting tariffs. Thus, the model needs to take into account capacity bookings and allowed revenues. This constraint is binding to every TSO individually. Nevertheless, the dependent variable is a specific tariff observed at a border. To reflect this, the model takes into account the average of allowed revenues of all TSOs $k = 1, \dots, m$ at border *i* in *t*, i.e. $\frac{\sum_{k=1}^{m} AR_{k,i,t}}{m_{i,t}}$. As for the same reason, we include the average of capacity bookings of all TSOs $k = 1, \dots, m$ at border *i* in *t*, i.e. $\frac{\sum_{k=1}^{m} CB_{k,i,t}}{m_{i,t}}$.

[12] This implies that all TSOs operate under the same regulatory regime. This is a valid assumption noting that the regulatory regime is in fact applied to all TSOs in a particular market area.

As tariff setting takes place prior to the tariff period the tariffs are valid for, and tariffs may not be changed during a tariff period, some of the variables used in the model refer to forecasts made by the TSOs. Changes in the market structure and to the networks do not happen on short-notice. Therefore, TSO are supposed to know how many TSOs operate how many IPs in the upcoming tariff period, and whether network users have a possibility of substitution. The same holds irrespective whether TSOs have captive demand or not, which is publicly available information. Hence, no forecasts are necessary concerning these two variables. In terms of congestion, this is different. A TSO cannot know for sure prior to the tariff period whether or not an IP will be congested. Therefore, the TSO has to predict this. The same holds for the capacity bookings. A TSO may already have contracts concluded before the tariff period, however, additional capacity bookings may be obtained during the tariff period. Forecasted capacity bookings at other TSOs are also unknown, and have to be predicted. Thus, the average capacity booking level per TSO is also a forecasted value. In contrast, a TSO knows the own allowed revenues applicable for the upcoming tariff period at the point in time the tariffs are set. On the other hand, a TSO is not aware of the allowed revenues of the other TSOs at the point in time the tariffs are set. Therefore, the average allowed revenues per TSO is also a forecasted value.

As the aim is to assess elasticities measuring relative changes, we use log-log models. In case a variable is a forecasted one, this is highlighted by a superscript *f*. As the models are estimated by fixed effects, a variable covering period fixed effects (β_t), such as general changes in costs of capital or in inflation, and one covering cross-section fixed effects (β_i) representing unobserved heterogeneity, are included. The models are then given by

$$\begin{aligned} ln\,(T^s_{i,t}) &= \beta^s_i + \beta^s_t + \beta^s_1\, dS_{i,t} + \beta^s_2\, dCD_{i,t} + \beta^s_3\, dCo^f_{i,t} \\ &+\beta^s_4\, ln\left(\frac{\sum_{k=1}^{m} AR^f_{k,i,t}}{m_{i,t}}\right) + \beta^s_5\, ln\left(\frac{\sum_{k=1}^{m} CB^f_{k,i,t}}{m_{i,t}}\right) + u^s_{i,t} \end{aligned} \tag{4}$$

whereby the selected sample *s* = minimum, maximum and median tariffs.

The expectation for the coefficients estimated, based on the theoretical analysis, depends on the regime of the data, to which the model is applied. For a regime, under which the TSOs face a volume risk, such as price-cap regime, we expect $\beta_1 < 0$ and $\beta_2 < 0$. In case an alternative TSO exists, tariffs are, ceteris paribus, expected to be lower (negative β_1) as compared to situation, in which a TSO is the only supplier of capacity at a border. In case TSOs have the possibility to shift revenues towards captive demand, we expect them to make use of this possibility to avoid competitive pressure, which, ceteris paribus, results in lower IP tariffs (negative β_2). If TSOs operate under a regulatory regime without any volume risk, such as a revenue-cap regime, there is no incentive to take account of other TSOs' tariffs when setting the own tariffs. Hence, we expect β_1 and β_2 to be insignificant.

As for congestion, we have no prior expectations for β_3. If β_3 is positive, the TSO anticipates the congestion, and applies higher tariffs to reflect the predicted scarcity. If $\beta_3 = 0$, the TSO does not anticipate congestion, even if the TSO expects congestion to arise. This behaviour can be based on the knowledge that the process of capacity marketing and allocation deals with (potential) congestion, so the TSO has no need to reflect this in the tariffs. This expectation holds for regulatory regimes with a volume risk to TSOs, and it does not hold for TSOs not exposed to any volume risk, as there are no incentives.

Derived from the revenue cap constraint, tariffs are, ceteris paribus, supposed to be higher if the allowed revenues increase. If capacity bookings increase, tariff should decrease. Therefore, we expect $\beta_4 > 0$ and $\beta_5 < 0$, independent of the regulatory regime applied. However, if we obtain insignificant β_4 and β_5, this may point at TSOs making use of revenue shifting towards domestic points. If at all, these may be insignificant in case TSOs operate under a regulatory regime implying a volume risk, such as a price-cap regime.

All our expectations apply to the minimum, the maximum, and the median tariff of border between market areas.

4.2 Data

In order to test the hypotheses using the empirical models, two data sets are necessary; one with TSOs, for instance, operating under a price-cap regime, one with TSOs, for instance, operating under a revenue-cap regime. In addition, the TSOs offering capacity need to be substitutes from a network users' point of view. Therefore, the data sets need to cover a market area, in which more than one TSO is operating. Furthermore, there need to be at least some borders within this market, where more than one TSO is operating.

Looking at the European gas markets, there is more than one TSO operating in Austria, France, Germany, Italy, Spain, The Netherlands, and in The United Kingdom (ENTSOG, 2019). For all of these countries, except for Austria and Germany, there is no border, where at least two TSOs offer capacity at an IP. Hence, there cannot be any competition. Although Austria has a few IPs connected with adjacent market areas, the border with Slovakia (IP "Baumgarten") is the only one, where both TSOs, namely Gas Connect Austria GmbH (hereafter: GCA) and Trans Austria Gasleitung GmbH (hereafter: TAG), offer capacity. Therefore, data for Austria may be used for the empirical analysis. However, national Austrian regulation prescribes the tariffs to be charged at all network points of all network operators. According to this, GCA and TAG are not free in setting tariffs, but are required to charge the same tariff at Baumgarten (E-Control, 2019). Therefore, the potential inter-TSO competition in Austria is resolved by national regulation; GCA and TAG cannot compete on tariffs.

Germany, with its two market areas GASPOOL and Net Connect Germany (hereafter: NCG) is currently the only EU Member State, where at least two TSOs are offering capacities at least at some borders. Unlike Austria, in Germany potential inter-TSO competition on tariffs is not restricted by national regulation. All TSOs in both German market areas operate under a revenue-cap regime. Therefore, we may only assess our hypothesis for revenue-cap regimes using panel data for German gas markets.

As for data on IP tariffs, we make use of a data set provided by ACER (2019a). This data set contains the cost of flowing 1 MWh through the respective IP on a firm basis in EUR/MWh for all IPs across Europe.[13] As German TSOs do not apply commodity charges, i.e. charges for the gas actually transported, such data refer to the capacity tariffs. In case different types of firm capacity are offered, the tariff refers to the best available capacity type. The time period covered by the data set is 2014 to 2018. Besides that, data of the IP's TSO, the border of connected market areas, and the flow direction are listed. In line with the empirical model the tariff data is grouped by borders distinguishing flow directions and gas qualities. Hence every group of data has either entry or exit

[13] In general, there are two categories of transmission capacities: Firm capacity grants the right to network users to transport gas without any risk of being interrupted. Interruptible capacity may be interrupted by the TSO, for example, to ensure security of supply (European Parliament and Council of the European Union, 2009). In some countries, for example, in Germany, different types of firm capacity may be offered. Their difference refers to potential conditions of firmness or gas routes. For additional information see BDEW (2019).

flow direction, and is either H- or L-gas. After having grouped the data per border, the number of TSOs being active at a particular border is determined. Not only is the number of TSOs operating at a border necessary to estimate the model, but also the number of TSOs at a border with captive demand. This information can be obtained directly from the TSOs' websites.

On an annual basis, ACER publishes a report on contractual congestion at interconnection points (ACER, 2019b). The findings of the reports covering the years 2014 to 2018 are linked to the IPs of the tariff data set. As for the analysis' data set, an IP may either be congested if the IP itself is congested, or if the adjacent IP is congested. In the latter case, an IP on the German side may have free capacity to offer, however, there is no corresponding capacity available on the other side of the border. Counting the congestion attribute gives the number of congested IPs as foreseen by the empirical model.

To control for changes in tariffs based on changes in allowed revenues, data on TSOs' allowed revenues for 2014 to 2018 are necessary. Even though TSOs operate under wide-ranging transparency obligations, allowed revenues are not published for the time period to be analysed. The main driver of the allowed revenues is the so-called *regulated asset base* (hereafter: RAB). Therefore, the RAB may be used as a proxy for the allowed revenues. However, also data on RAB are not available for the past. TSOs' annual reports, however, show the value of fixed assets. Fixed assets and RAB are based on the same items, and are supposed to be strongly correlated. The difference solely refers to differences in depreciation periods. Therefore, we use the book value of fixed assets as a proxy for the RAB to determine the forecasted allowed revenues as foreseen by the model. There are also joint venture pipelines, whose capacity is offered by the shareholder TSOs. In such a case, we allocate the value of fixed assets directly to the shareholders based on the ownership structure.

Data on capacity bookings are collected from the transparency platform operated by ENTSOG (2019). This transparency platform publishes IP data, i.a. data on capacity bookings. Data availability for German TSOs starts in October 2013. Capacity bookings are distinguished in firm and interruptible. In determining tariffs, interruptible capacity is usually given a discount to compensate for the risk of being interrupted. In return, this means that a booking of one unit of firm capacity contributes more to obtaining revenues than a booking of one unit of interruptible capacity, because of the discount. Also, within the group firm capacity bookings, there are differences. There are different types of firm capacities that may be offered at a particular IP. These different types may receive a discount due to quality differences. Furthermore, a so-called multiplier may be added to capacity booking, to firm as well as to interruptible capacity, with the intention to stimulate long-term bookings by making them relatively cheaper compared to short-term bookings. Also, seasonal factors may be applied. All these may cause an inaccuracy of data. The capacity bookings reported by the transparency platform are aggregated bookings of network users. However, the value of one unit of capacity booked may be higher or lower, depending on discounts granted and multipliers applied. Such information is not available, which needs to be taken into account analysing the estimates of the empirical model.

As tariffs of a TSO are based on the sum of all forecasted capacity bookings, it is not sufficient to consider IP bookings only. The ENTSOG transparency platform also shows capacity at domestic points. In detail, the platform contains for every TSO all capacity bookings levels, except for capacity towards downstream distribution system operators for supplying households. However, we may assume this capacity to be relatively constant over time, hence, it is captured by the period fixed effects. Therefore, there is no need to consider these data, which are also not available for all TSOs for the respective period.

The model in Section 4.1 foresees the dummy indicating congestion, the average RAB, used as a proxy for the average allowed revenues, and the average capacity bookings to be forecasted values. Therefore, a decision has to be made on how to forecast these values. We suppose the best forecasted values to be the latest actual values. Therefore, the forecast for data in t shall be data of t-1, i.e. lag 1 data. This means that $dCo_{i,t}^{f} = dCo_{i,t-1}$, $CB_{k,i,t}^{f} = CB_{k,i,t-1}$, and $RAB_{k,i,t}^{f} = RAB_{k,i,t-1}$. For consistency reasons, averages are calculated for the number of TSOs in t-1 as well. In the remainder we drop time indices, and indicate lags by supplement (-1). As a consequence of using lagged variables, the time period of the analysis covers 2015 to 2018. Introducing lagged dependent variables avoids the endogeneity bias due to reverse causation.

Exploring the compiled data set reveals another market merger involving Belgium and Luxembourg has taken place during the period of observation. In order to keep a balanced panel, we treat this merger as the gas market area of Luxembourg had not existed before the merger, and is directly integrated in the Belgian one. This means, we omit the observations for the one IP connecting Luxembourg and NCG until the merger, and consider this IP as another substitute to the other IPs connecting NCG and Belgium afterwards. After this change, the data set shows strongly balanced panels with borders $i = 1, \dots, 35$ and $t = 2015, \dots, 2018$, i.e. four observations for 35 cross-sections.

Figure 2 plots the sum of the book value of the fixed assets, and capacity bookings for firm and interruptible capacities for all German TSOs in 2014 to 2018 using an indexed representation with 2014=100%. The figure shows a positive trend for the sum of fixed assets during the period with a compound annual growth rate (hereafter: CAGR) of 5.45%. Firm capacity is constant over the period (CAGR: -0.02%). In contrast, interruptible capacity bookings show a negative trend (CAGR: -7.66%).

Table 1 shows the distributions of the total number of TSOs, the number of TSOs with captive demand, and the number of congested IPs. For the number of TSOs being active at border, most observations show only one TSO offering capacity at border (43.64%). However, also two TSOs (31.52%) and three TSOs (21.21%) appear relatively often. For the number of TSO with captive demand, the distribution is slightly different. 87.27% of the observations show either one TSO with captive demand (47.88%) or two (39.39%). Three TSOs with captive demand are observed in 9.70% of all cases. In a very few cases (1.21%), a border does not have any TSO with captive demand. In terms of congestions, 81.21% of all IPs are not congested. Compared to this, one IP (10.91%), two IPs (6.06%), or three IPs (2.82%) being congested is observed not that often.

A joint distribution of the total number of TSO and the number of TSOs having captive demand (Table 2) shows that in case only one TSO offers capacity at a border, there are only two observations with a TSO having no captive demand. Additionally, there are no observations with more than one TSO, whereby at least one TSO has captive demand. For the empirical model, this implies that $dCD = 1$ if $dS = 1$. However, if $dS = 0$, $dDC = 0$ only in two cases. Based on only two observations, no reliable estimates for dCD can be expected. Therefore, we drop the variable from the model, and assume $dDC = 1$. In terms of dS, the dummy is 0 in approximately 44% of all observations, and 1 in about 56%. Hence, the data set is fairly balanced in this respect.

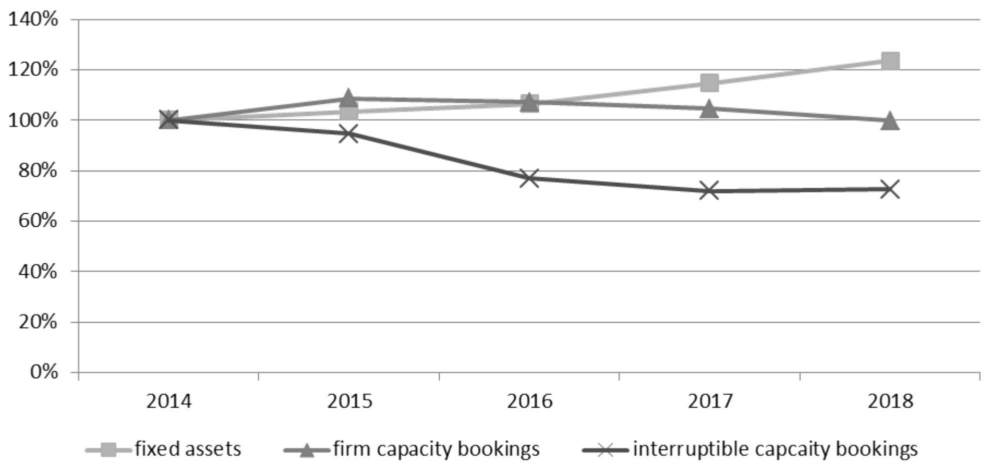

Figure 2: Index representation of the sum of fixed assets, firm capacity bookings and interruptible capacity bookings for all German TSOs in 2014 (=100%) to 2018. Source: Bundesanzeiger (2019) and ENTSOG (2019); own calculations.

Table 1: Distribution of TSO (all and captive demand) and congested IPs in the sample in 2014-2018

Number	TSOs (total)		TSOs (captive demand)		Congested IPs	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0	0	0	2	1.21	134	81.21
1	72	43.64	79	47.88	18	10.91
2	52	31.52	65	39.39	10	6.06
3	35	21.21	16	9.70	3	2.82
4	6	3.64	3	1.82	0	0
Total	165	100	165	100	165	100

Table 2: Joint distribution of TSOs with captive demand, and number of all TSOs in the sample in 2014-2018

Total	Number TSOs (captive demand)					
number TSOs	0	1	2	3	4	Total
1	2	70	0	0	0	72
2	0	6	46	0	0	52
3	0	0	19	16	0	35
4	0	3	0	0	3	6
Total	2	79	65	16	3	165

To check the data set for stationarity, unit root test may be applied. However, the power of these tests is low due to the sample size. Results of testing for cointegration are also not reliable given the length of the time series. Nonetheless, there is a mathematical relationship between tariffs, allowed revenues and capacity bookings, i.e. the capacity constraint as pointed out in Section 2.2. Therefore, we expect the variables to be cointegrated. Hence, the regressions are not spurious, and the estimators are consistent.

4.3 Results

Table 3 shows the results estimating the model developed in Section 4.1, including the adjustments made in Section 4.2, for minimum, maximum, and median tariffs at borders by fixed effects. dS is the dummy variable denoting the difference between borders where more than on TSO offers capacity ($dS = 1$) and where capacity is offered only by one TSO ($dS = 0$). $dCO(-1)$, being a lagged variable, points out the difference between congested and non-congested borders $ln\left(\frac{\sum_{k=1}^{m} RAB_k\ (-1)}{m(-1)}\right)$ is the average RAB per TSO active at a border whilst $ln\left(\frac{\sum_{k=1}^{m} CB_k\ (-1)}{m(-1)}\right)$ stands for the average total capacity bookings per TSO active at a border; both use lag (1) data as a forecast in line with model as set out in Section 4.2.

In case more than one TSO is offering capacities at a border, network users have a choice between substitutes. In general, tariffs appear to lower in situations, where capacity at border is offered by more than one TSO. In detail, if more than one TSO offers capacity at a border, minimum tariffs are 51.61% lower, maximum tariff are 7.83% lower, and median tariffs of the border appear 28.54% lower. In a one-tail test, which is in accordance with our hypothesis, all three estimates are significant a 1% level.

Referring to forecasted congestions, the estimates do not show a significant effect of IP congestion on tariff setting in two-tail significance tests.

The estimated marginal effect of the forecasted average allowed revenues is -0.02% in case of the minimum tariffs, 0.23% for maximum tariffs, and 0.38% in case of median tariffs. Whereas the estimates for the median (p < 1%) and the maximum tariffs (p < 5%) are significant, the estimates for the minimum tariffs are insignificant (p > 10%).

The estimated marginal effect of the forecasted average capacity bookings is -0.17%, -0.15%, and -0.23% (minimum, maximum, median tariffs), with p < 1% for both maximum and median tariffs, and being insignificant in case of minimum tariffs.

For the period fixed effects, the estimates appear to be insignificant (p > 10%), with two exceptions in 2016 concerning maximum and median tariffs (both -0.04% with p < 10%).

As stated in Section 4.1, the expected signs of the coefficients depend on the regulatory regime that is applied to the TSOs of data set used for the analysis. The results in Table 3 are the estimates using data of TSOs operating under a revenue-cap regime, i.e. regulatory regime without any volume related risk to the TSOs.

Comparing the results obtained with our expectations, there is a positive coefficient related to the forecasted average allowed revenues, as expected. Furthermore, estimates for the forecasted average capacity bookings are negative, as expected. Hence, we could verify the revenue cap constraint. However, both estimates related to minimum tariffs appear to be insignificant. It could be argued that taking recent actual data are not the best forecast. Nevertheless, it seems to be an appropriate forecast looking at the p-values of estimates for maximum and median tariffs. Additionally, looking again at Figure 2, the data for capacity bookings and fixed assets do not show much variation but rather follow a trend. If the answer as to why the estimates are insignificant for minimum tariffs while being significant for maximum and median tariffs, and knowing the revenue cap constraint is binding, seems to be not data related, it is supposed to be related to the TSOs' behaviour. Insignificant marginal effects indicate that TSOs do not increase or decrease tariffs at IPs in relation to changes in allowed revenues or capacity bookings. This is an indication that TSOs may set the tariffs in response to each other. Such behaviour observed for the minimum tariffs was expected for TSOs operating under e.g. a price-cap regime. However, the TSOs, whose tariffs are analysed, operate under a revenue-cap regime, under which such behaviour was not expected.

As for congestions, the results suggest TSOs do not consider congestion in setting tariffs. This raises the question how TSOs deal with expected scarcity. In practice, capacity allocation takes place in line with the rules stated in the so-called *CAM Network Code* (European Commission, 2017a). These rules lay down that capacity is marketed via auction procedures. During the auctions, the price of the auctions, i.e. the tariffs, is increased in case, and as long as, demand exceeds supply. Hence, there is no need for a TSO to take scarcity and congestion into account in setting tariffs as this is dealt with by the auction procedures.

The variable dS indicates whether a network user has a choice between different TSOs' IPs at the border of interest. For a regulatory regime without a volume risk, like a revenue-cap regime, the theoretical assessment expects (in the short term) no significant difference in tariffs between borders, at which a TSO is the only supplier of capacity, i.e. $dS = 0$, and multiple TSOs offering capacity at a border, i.e. $dS = 1$, leading to substitutes for network users. The results show that for all dependent variables, the minimum (-51.61%), maximum (-7.83%) and median tariff (-28.54%), are significantly lower in case more than one TSO offers capacity at a border. Such results point at tariff adjustments made by TSOs as a response to the existence of substitutes to network users. According to our theoretical analysis, such behaviour was not expected since German TSOs operate under a revenue-cap regime. Based on this, however, we cannot unambiguously accept or reject the existence of tariff competition between regulated TSOs in in Germany.

Table 3: Estimates for the period 2015-2018: Dependent variables $ln\,(T^{min})$, $ln\,(T^{max})$, and $ln\,(T^{median})$ (robust standard errors in parentheses, cross-section fixed effects are not reported).

	$ln\,(T^{min})$	$ln\,(T^{max})$	$ln\,(T^{median})$
dS	-0.5161***	-0.0783***	-0.2854***
	(0.0605)	(0.0196)	(0.0199)
$dCO(-1)$	-0.0887	0.0028	0.0030
	(0.0767)	(0.0398)	(0.0440)
$ln\left(\frac{\sum_{k=1}^{m} RAB_k\,(-1)}{m(-1)}\right)$	-0.0176	0.2319**	0.3753***
	(0.3250)	(0.0883)	(0.0844)
$ln\left(\frac{\sum_{k=1}^{m} CB_k\,(-1)}{m(-1)}\right)$	-0.1702	-0.1523***	-0.2298***
	(0.1742)	(0.0465)	(0.0484)
Constant	4.0201	-1.5079	-2.3320
	(3.5598)	(1.7745)	(1.5744)
Period fixed effects			
2016	-0.0866	-0.0373*	-0.0412*
	(0.0624)	(0.0196)	(0.0217)
2017	-0.0791	-0.0179	-0.0328
	(0.0772)	(0.0241)	(0.0251)
2018	-0.0164	0.0464	0.0143
	(0.0592)	(0.0352)	(0.0322)
observations[14]	131	131	131

Two-tailed p-values: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

[14] One observation is dropped from the regressions due to the condition dCD =1, see Section 4.2. Considering this observation, mainly impacts the estimates concerning the minimum tariff.

4.4 Controlling for structural differences to explain the results

A possible explanation for the empirical results may be due to structural differences between TSOs. Two groups of networks and TSOs respectively may be distinguished: On the one hand, there are wide-ranging meshed networks to transport gas to industrial customers, and to distribution systems, in order to supply end customers. On the other hand, there are transit TSOs, which function as a kind of interconnector between two markets. Making this distinction, therefore, also points again at the possibility to shift revenues to be obtained between different network points, in particular between IPs and domestic points.[15]

To check for structural differences between transit and meshed TSOs, a subset of the sample is created containing only those observations, where capacity is offered at a border by both groups of TSOs, at least one meshed and at least one transit TSO. Such a subset allows for assessing how often the minimum, maximum, and median tariff is charged by a transit or by a meshed TSO (see Table 4 in Appendix A). It appears that minimum tariffs are particularly charged by transit TSOs, whereas maximum tariffs are particularly charged by meshed TSOs. This hints at structural differences between transit and meshed TSOs.

In order to verify the existence of structural differences between transit and meshed TSOs impacting the tariffs, the empirical model is applied to two different subsets containing only transit (subset 1) or only meshed TSOs (subset 2). If there was a structural difference between the two groups of TSOs, we would not expect a large and statistically significant effect of having more than one TSO operating at a border on the tariffs for each of the subsets. The resulting estimates are compared with the estimates using the full sample as Table 3.[16] This comparison points at no general differences in the subsets as compared to the full sample. As for subset 1, there are no observations. Regarding subset 2, for example, minimum tariffs also appear to be more than 50% lower in case more than one TSO offers capacity at a border. These results obtained for this subset are similar to the estimates obtained using the full sample.

We find that transit TSOs in a vast majority of cases charge the minimum tariffs, and at the same time we find a large and statistically significant effect of having more than one TSO offering capacity at a border on tariffs within the group of meshed TSOs. Based on these findings, we conclude that differences between transit and meshed TSOs do not sufficiently explain the differences in tariffs between TSOs facing substitute TSOs and TSOs who do not.

Analysing the subsets assumes homogeneous TSOs within each group. However, it may be argued even the group of meshed TSOs is rather heterogeneous. The meshed TSOs directly or indirectly, via a connection to distribution networks, transport gas to end customers. Nevertheless, some, but not all, meshed TSO also can be used for transit gas in case they are connected to different gas markets. Also, the number of markets a TSO is connected to varies. So, it appears the group of meshed TSOs seems rather heterogeneous.

Not only the TSOs' networks are different, but also the extent to which they have been impacted by a market merger. When markets are merged, less capacity is subject to bookings (Keller et al., 2019). The loss of revenues is redistributed to the remaining capacity to be booked. As only the level of (forecasted) booked capacities has an impact on the tariffs, tariffs, ceteris paribus, increase if booked capacity decreases. Such a decrease also results from market mergers. All the

[15] See Sections 2.2 and 3.

[16] The comparison of the estimates is provided in Appendix A.

market mergers Germany has been faced with are supposed to have had a different impact on each of the TSOs involved.

Market mergers may also impact the quality of capacity products offered. When gas markets are merged, TSOs, for example, have to cope with new possible flow scenarios. Such flows may not, or may only be possible under certain conditions. Such conditions, for instances, may be linked to temperature, demand scenarios, or specific routes (ACER, 2019c). The restrictions on capacity types induced by market mergers differ per TSO, depending on the individual network, and at what actual borders a merger has taken place, i.e. to what extent the respective TSO has been affected by a merger. Keller et al. (2019) found, that not only the network tariffs matter to network users in making a booking decision between alternatives, but also the quality, i.e. the capacity type, matters. In Germany, around 48% of capacity offered at IP is conditional capacities (Grant Thornton et al., 2019). As stated in Section 4.2, the data set used for the empirical analysis does not distinguish between different capacity types. Given that transparency obligations do not require TSOs to publish all historic tariff data for all capacity types, we are not able to control for quality differences in this empirical analysis.

5 Conclusions

Merging gas markets can allow network users to choose between transport substitutes, which are offered by different TSOs. This is the case in Germany. When network users make efficient choices, they are sensitive to tariff differences, which implies that inter-TSO competition may be possible at certain borders of merged gas markets (Keller et al., 2019).

Our paper extends the literature on (de-)regulation of natural monopolists. It has a different view as compared to other work, for example Laffont and Tirole (1996), as the potential competition arises from merging market with regulated monopolists, and does not arise from unregulated new entrants in the market. In contributing to the future of tariff regulation in European gas markets, our focus differs from other studies and research, which do not take account of market mergers and their impact on the potential for inter-TSO competition (For example, see Cervigni et al., 2019; EY and REKK 2018; Hecking, 2015).

The theoretical analysis of this paper shows that TSOs have an incentive to engage in tariff competition depending on the regulatory framework applied. On the one hand, under regimes imposing a volume risk to TSOs, such as a price-cap regime, TSO are supposed to compete on tariffs. As a consequence, they are supposed to lower tariffs at competitive cross-border interconnection points, and raise tariffs in particular for domestic customers, who cannot switch to other network points. On the other hand, if TSOs in a merged market area operate under a regulatory regime without any volume risk, such as a revenue-cap regime, there are no incentives to engage in tariff competition as the TSOs are ensured obtaining their allowed revenues by the regulatory regime applied. In analysing a panel (2015-2018) of tariffs charged by German TSOs, we find tariffs being up to 52% lower in situations, where capacity at border is offered by more than one TSO. As this finding is not what we expected given a revenue-cap regulation, we have tested whether these results are due to specific circumstances.

An additional analysis shows that a differentiation between transit and meshed networks does not provide a sufficient explanation for this result. Hence, the mechanism by which the regulatory regime affects tariff setting may be different (more complex) than we have assumed. Specific elements of the regulatory regime applied may explain why in case more than one TSO offers capacity at a border, tariffs are lower, even if these TSO operate under a revenue-cap regime. For example, a TSO may expect a lower utilisation of its infrastructure in the future if its tariffs are above those of other TSOs offering the same service to network users. The firm may then expect the regulatory authority to grant a lower compensation for the costs spend in the future, as a lower utilisation indicates the infrastructure is less needed. This would cause a decrease in the allowed revenues and, ceteris paribus, in profits. Even if a lower utilisation may not directly lead to lower allowed revenues, it may indirectly do so. TSOs are usually exposed to efficiency benchmarking. If there is a structural decrease in utilisation, ceteris paribus, the firm's efficiency decreases as well, which may result in lower allowed revenues. In some cases, TSOs may also be restricted in their freedom in determining tariffs, or may be restricted in adjusting tariffs from one tariff period to the next. Future research may further investigate these aspects. Based on our empirical analysis, we find that German TSOs are sensitive in their tariff setting to the ability of network users to choose among a number of TSOs despite the fact that these TSOs do not face a direct volume risk in the tariff regulation. Further research is required to determine how the regulatory process precisely influences the optimal tariff setting of the TSOs subject to revenue-cap regulation operating in merged market areas. Hence, it cannot unambiguously be answered, whether effective inter-TSO competition on tariffs exists in Germany.

Given our results, regulatory authorities may consider applying a dual-till approach to regulate TSOs in merged markets, with the aim of allowing competition where possible.[17] Applied to gas markets, competition may be possible at cross-border interconnection points, however, captive demand needs to be protected from suffering from the regulatory change. Hence, such a dual-till approach would consist of cross-border points being exposed to a price-cap regulation, while all other network points are exposed to a revenue-cap regulation. In addition, and to enhance the inter-TSO competition introduced by such a dual-till approach, more flexibility should be given to the regulated TSOs in setting competitive tariffs, for example, dynamic tariff adjustments instead of fixing tariffs for a tariff period. Being exposed to such a regulatory regime, TSOs may claim an increase of risk to their business, and ask for an adequate risk premium to be considered setting their allowed revenues. This, and other potential side effects of a dual-till approach applied to TSOs in merged markets may be covered by future research.

[17] In regulating (private) airports, a distinction is made between aeronautical and non-aeronautical services. Under a so-called single-till regulation, both areas are combined in terms of revenue regulation. Alternatively, under a dual-till regulation, aeronautical services are regulated whereas non-aeronautical services are out of the regulatory scope. For example, see Bilotkach et al. (2012) and Czerny (2006).

Appendix A: Analysis of structural differences between transit and meshed TSOs using subsets

To explore potential structural differences between transit and meshed TSOs, we create a subset containing all borders, at which at least one transit TSO and at least one meshed TSO offers capacity. This subset consists of 41 observations. Table 4 illustrates how often the minimum, maximum, and median tariff is charged by a transit or by a meshed TSO. It appears that minimum tariffs are particularly charged by transit TSOs, whereas maximum tariffs are particularly charged by meshed TSOs.

Table 4: Distribution of $\boldsymbol{ln}\ (\boldsymbol{T^{min}})$, $\boldsymbol{ln}\ (\boldsymbol{T^{max}})$, and $\boldsymbol{ln}\ (\boldsymbol{T^{median}})$ charged by transit or meshed TSOs. Cover period 2015-2018.

T^{min} charged by		T^{max} charged by		T^{median} charged by		
Transit TSO	Meshed TSO	Transit TSO	Meshed TSO	Transit TSO	Meshed TSO	Transit and meshed TSOs
35	6	3	38	9	18	14
85.37%	14.63%	7.32%	92.68%	21.95%	43.90%	34.15%

To verify structural differences between transit and meshed TSOs, the empirical model is estimated using the full sample and the two subsets as defined in Table 5. The results are shown in Table 6. As there are no observations for subset 1, the table allows for a comparison of the full sample and subset 2 only.

Table 5: Definitions and number of observations of data sets used for a subset analysis. Covered period 2015-2018.

Data set	Definition	Observations
Full Sample	All borders as used in Section 4.3 of this paper	131
Subset 1	All borders, at which only transit TSOs offer capacity	0
Subset 2	All borders, at which only meshed TSOs offer capacity	88

Table 6: Estimates for different data sets for the period 2015-2018: Dependent variables $ln\ (T^{min})$, $ln\ (T^{max})$, and $ln\ (T^{median})$ (robust standard errors in parentheses, cross-section fixed effects are not reported).

	$ln\ (T^{min})$		$ln\ (T^{max})$		$ln\ (T^{median})$	
	Full sample	Subset 2	Full sample	Subset 2	Full sample	Subset 2
dS	-0.5161***	-0.5425***	-0.0783***	-0.0793**	-0.2854***	-0.2725***
	(0.0605)	(0.0218)	(0.0196)	(0.0315)	(0.0199)	(0.0263)
$dCO(-1)$	-0.0887	-0.1223**	0.0028	-0.0903***	0.0030	-0.1264***
	(0.0767)	(0.0503)	(0.0398)	(0.0243)	(0.0440)	(0.0281)
$ln\left(\frac{\sum_{k=1}^{m} RAB_k\ (-1)}{m(-1)}\right)$	-0.0176	0.4282***	0.2319**	0.2780***	0.3753***	0.3648***
	(0.3250)	(0.1030)	(0.0883)	(0.0786)	(0.0844)	(0.0803)
$ln\left(\frac{\sum_{k=1}^{m} CB_k\ (-1)}{m(-1)}\right)$	-0.1702	-0.2510***	-0.1523***	-0.1774***	-0.2298***	-0.2249***
	(0.1742)	(0.0567)	(0.0465)	(0.0397)	(0.0484)	(0.0388)
constant	4.0201	-2.8622	-1.5079	-1.7757*	-2.3320	-2.2735
	(3.5598)	(2.4393)	(1.7745)	(0.9597)	(1.5744)	(1.3952)
Period fixed effects						
2016	-0.0866	-0.0747**	-0.0373*	-0.0753***	-0.0412*	-0.0676**
	(0.0624)	(0.0343)	(0.0196)	(0.0228)	(0.0217)	(0.0239)
2017	-0.0791	-0.0777**	-0.0179	-0.0582**	-0.0328	-0.0729***
	(0.0772)	(0.0285)	(0.0241)	(0.0267)	(0.0251)	(0.0245)
2018	-0.0164	-0.0365	0.0464	0.0153	0.0143	-0.0173
	(0.0592)	(0.0377)	(0.0352)	(0.0357)	(0.0322)	(0.0315)
observations	131	88	131	88	131	88

Two-tailed p-values: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

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